Condition Monitoring in Steel Industry —
Hopes and Disillusions

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In the former multilayered vertical hierarchies of manufacturing companies, **maintenance** was for a long time assigned to sprawling centralised units. However, like all large organisational units with cross-departmental tasks, these central service providers had considerable weaknesses. They were unable to act quickly, and they were also hampered by a lack of decision-making freedom which might have allowed them to respond effectively and flexibly. The productive aspect of Total Productive Maintenance (TPM) – now widely recognised to be the correct approach – could not be activated in this scenario. Only slowly did people come to realise that their production plants could be run more reliably by bundling the responsibilities for plant, products and costs in smaller, more manageable and decentralised operational units, down to level of manufacturing islands and teams, than with the previous function-oriented, cumbersome structures.

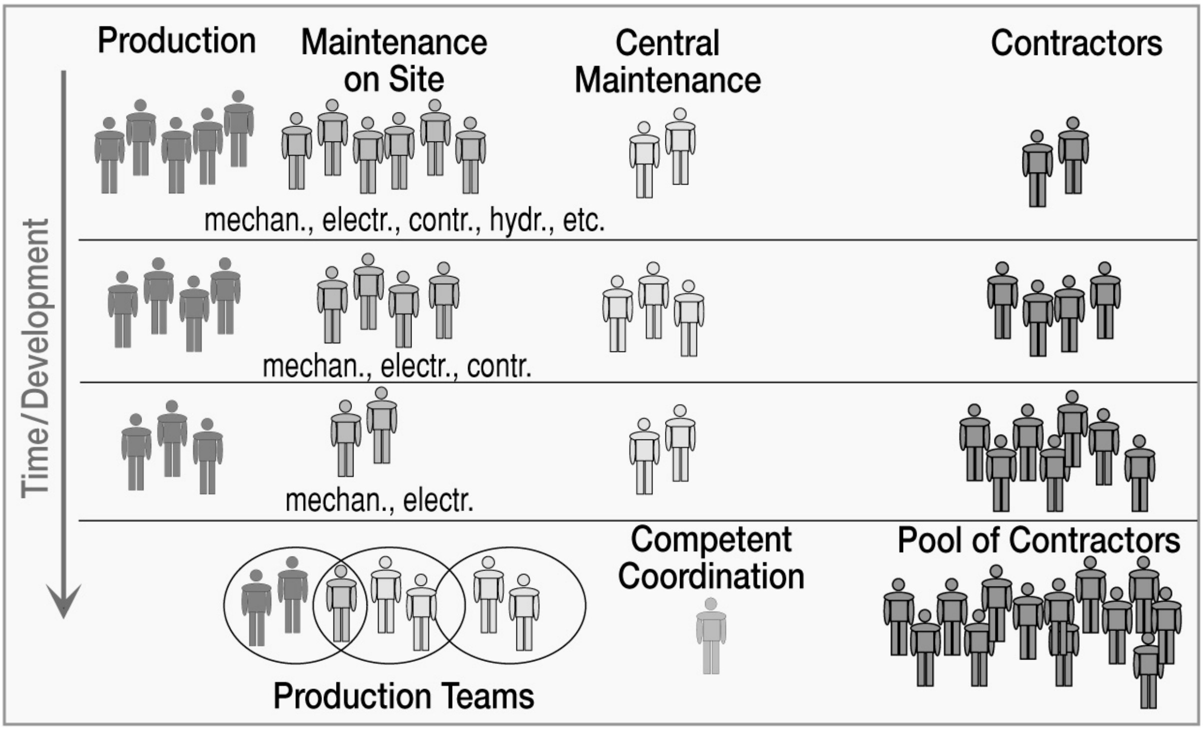

Fig. 1: Change of Maintenance Structures

At the same time, this signalled the end of the era in which manufacturing companies could call on the services of relatively strongly staffed in-house maintenance departments, central workshops and other departments employing skilled mechanics, electricians and measuring and control specialists. As workforces slimmed, vast numbers of these experts were no longer available. It became necessary to transfer operative maintenance responsibilities directly to the production shop and to buy in services from contractors (1).

Production and maintenance functions are gradually changing into internal customer-supplier relationships, in the steel industry as elsewhere. In the process, attempts are being made to build interdisciplinary teams to utilise the knowledge of the various people involved to the fullest extent and to apply it to as wide a range of plant and equipment as possible (fig. 1). It has become clear, however, that the cuts in staffing, which have been particularly severe in the steel industry, have resulted in a great loss of expertise. The question arises as to how the increasingly high requirements on plant and equipment reliability are to be met with the personnel still remaining. The greatest loss, however, has been the knowledge of skilled personnel running the machine on site who had developed an instinct for recognising whether their machines were generating unusual noises, excessive temperatures, or were otherwise operating 'out-of-spec', and who responded appropriately – and usually correctly. On-the-spot feedback like this is hardly available today, since scarcely anyone remains in the vicinity of essential process equipment for any length of time. This development alone should compel us to install condition monitoring procedures if the efficiency and reliability of production are not to be endangered.

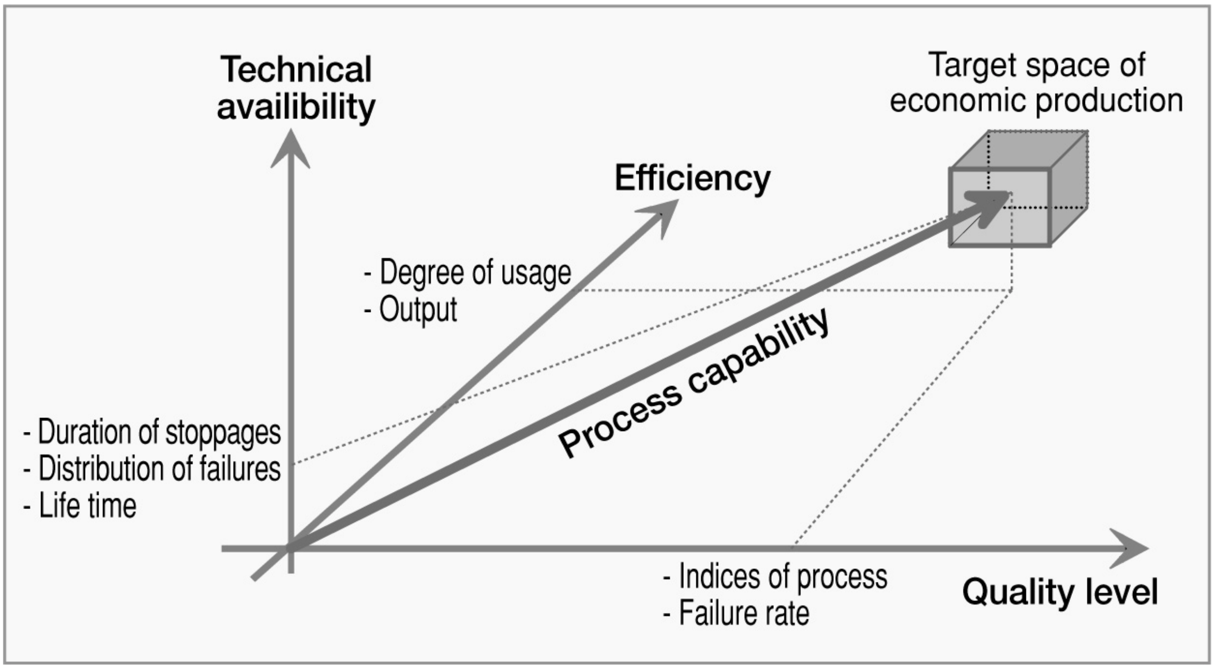

Fig. 2: Criteria for Judging and Controlling of Processes

The main goal of industry today is to achieve customer-oriented production with high added value. Customer orientation demands guaranteed **process capability** throughout the entire production system. A company can only maintain its process capability when it succeeds in maintaining an optimum balance between the goals of efficiency, quality and technical safety (fig. 2). **Maintenance** can have a major influence on all three of these parameters. Let us take a closer look at the goals of “quality” and “safety” as an availibility factor.

Objective: "Quality"

In previous years the standards set for measuring productivity and performance have at best been variable. Measurement was carried out in relation to bonus schemes and budgets but other improvement processes were difficult to initiate. The quality initiative has brought into focus the need for indices as a means of achieving continuous improvement (2). More companies are now engaged in internal and external benchmarking to check that improvement is taking place and that their competitive position is being maintained. Standards are improving, and there is a growing acceptance of the need to measure performance.

If a company wants to survive on the market, ie obtain certification of its quality management, it has to comply with the hitherto existing standard EN/ISO 9002, section 4.9 “Process Control", which reads*: "The supplier shall identify and plan the production, installation and servicing processes which directly affect quality and shall ensure that these processes are carried out under controlled conditions. Controlled conditions shall include (besides others) suitable **maintenance of equipment** to ensure continuing process capability."

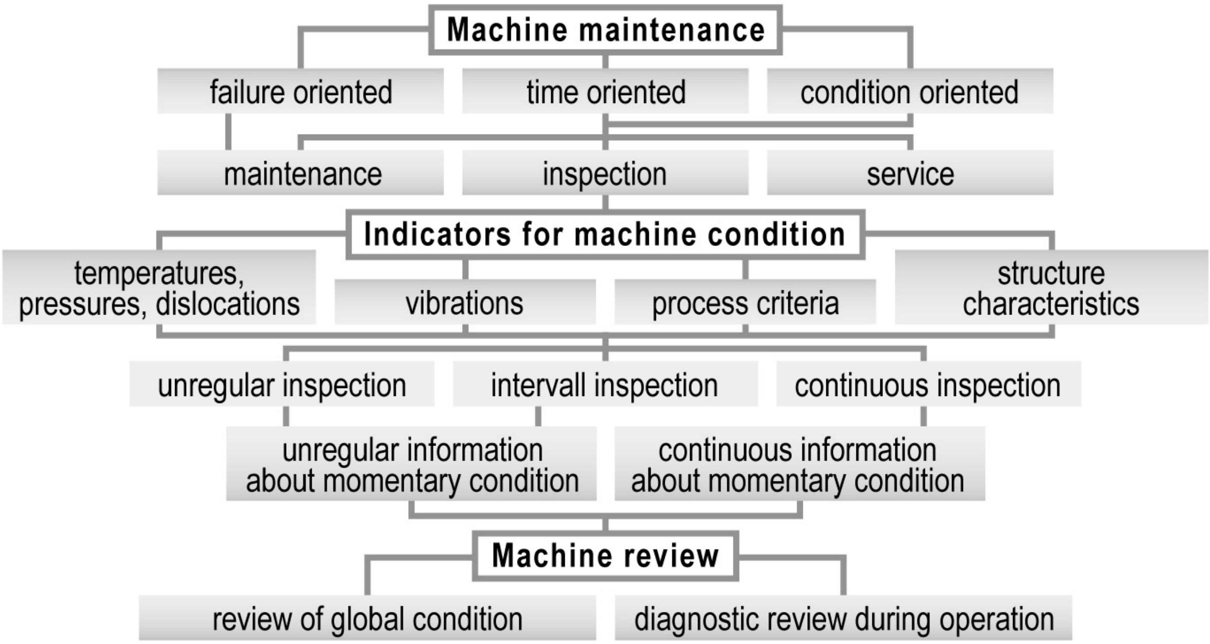

Fig. 3: Ways of Condition Monitoring

Within the scope of machine maintenance it is therefore essential to put in place and operate a monitoring system capable of supplying suitable indicators of machine condition (fig. 3) (3). These indicators should above all be obtainable wherever the product comes into direct contact with the machines that process it, eg in continuous casters, hot and cold rolling mills or finishing lines in steel making procedure. Whenever the machine conditions are not within specification, the product may develop defects that can diminish its quality or lead to claims. However, before a process can be monitored, it is necessary to determine the permissible values for certain parameters. This allows the definition of ranges within which directly measured or derived values and data relating to the process, equipment and the product may vary. Any deviation from the set range could lead to malfunctioning of the plant or to defective products.

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* See also Draft EN/ISO 9001-2000, sect. 7.5.1 and 9004-2000, sect. 8.2.2; 8.2.3

Example: “Vibration monitoring on rolling stands”

One way of controlling the quality level is at the steel forming stage. During cold rolling, chatter marks appearing on the sheet as a result of the rolling process can considerably diminish the quality of the product. Examples such as described by Voest-Alpine Stahl Linz GmbH (4) or Bethlehem Steel Corp. (5) illustrate very well how equipment monitoring can simultaneously improve product quality:

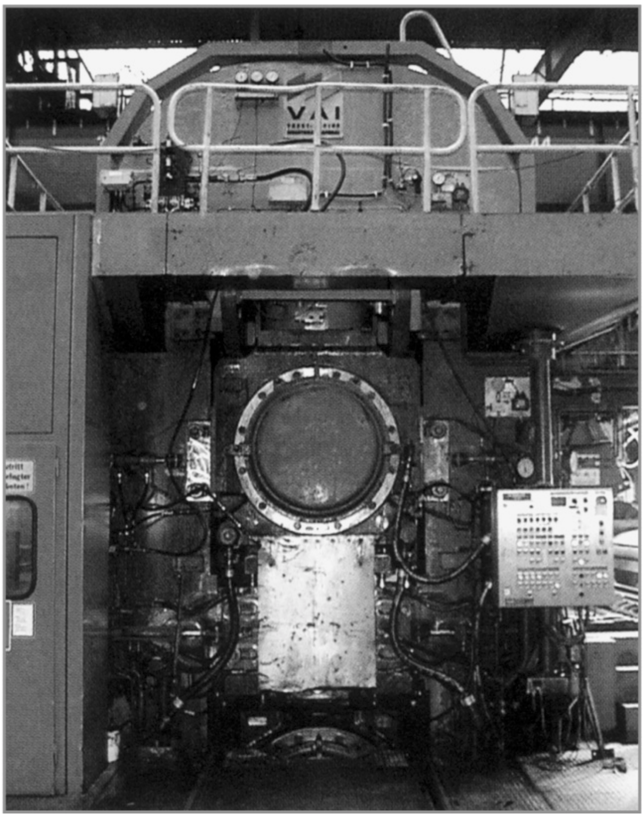

Fig. 4: Condition Monitoring at a Temper Mill

At a temper mill a monitoring system for chatter and bearing control was installed by Voest (fig 4). A 2-axis sensor, fixed at the chocks of the upper working roll, measures vibration. As it was not possible to detect clearly defined chatter vibrations by using accelerators at the top of the stand, a fixed mounting device for the sensor was installed to every chock of the working roll. The operator fastens the sensor with a simple screw.

Data are analysed simultaneously with information about speed, force and tension. The output generates a warning to the operator and informs him about chatter conditions during the rolling process. The operator is able to change the rolling process manually by correcting speed, tension, force and working rolls or he chooses automatic control, which reduces production speed automatically to an uncritical vibration level. Visualisation is done by a simple traffic light (fig. 5). Over a monitor he can have additional information about rolling conditions.

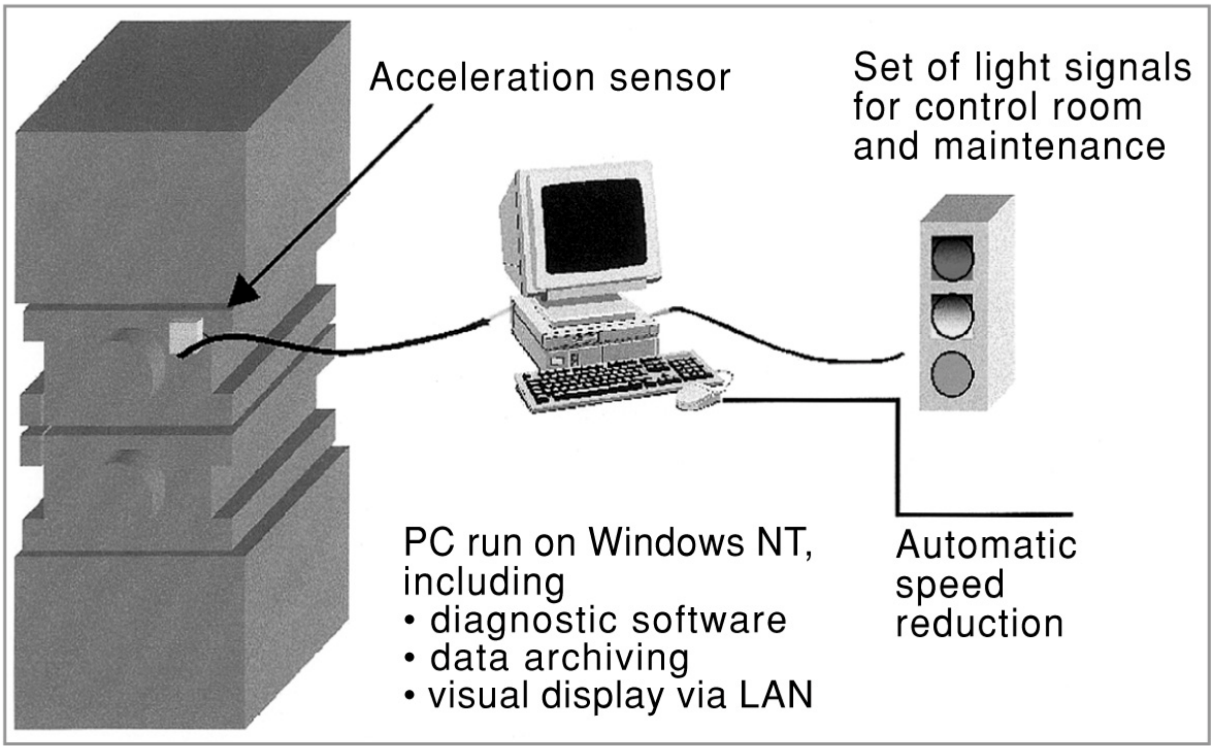

Fig. 5: Basic principle of mill stand vibration monitoring

With statistical analysis of vibration (skewness and kurtosis) bearing defects can be detected easily. The advantage of statistical analysis compared to spectral analysis is based on the numerical efficiency and simplicity for recognising non periodic vibrations. In fig. 6 a simple detail of a bearing defect of a working roll is shown, where kurtosis increases due to a bearing defect of an inner ring (4). During the gap time working rolls had been changed.

Installation and optimisation of this chatter control system at Voest in 1999 took about one year. Since then nearly no strips with chatter marks had been produced. The pay back time for this system only amounts to about half a year. In securing process capability, it is important for systems like these that they are not installed separately as a black box which would prevent anyone identifying with the system and the data it provides. The described monitoring system is completely integrated in the control room of the temper mill and has been fully accepted by the operators.

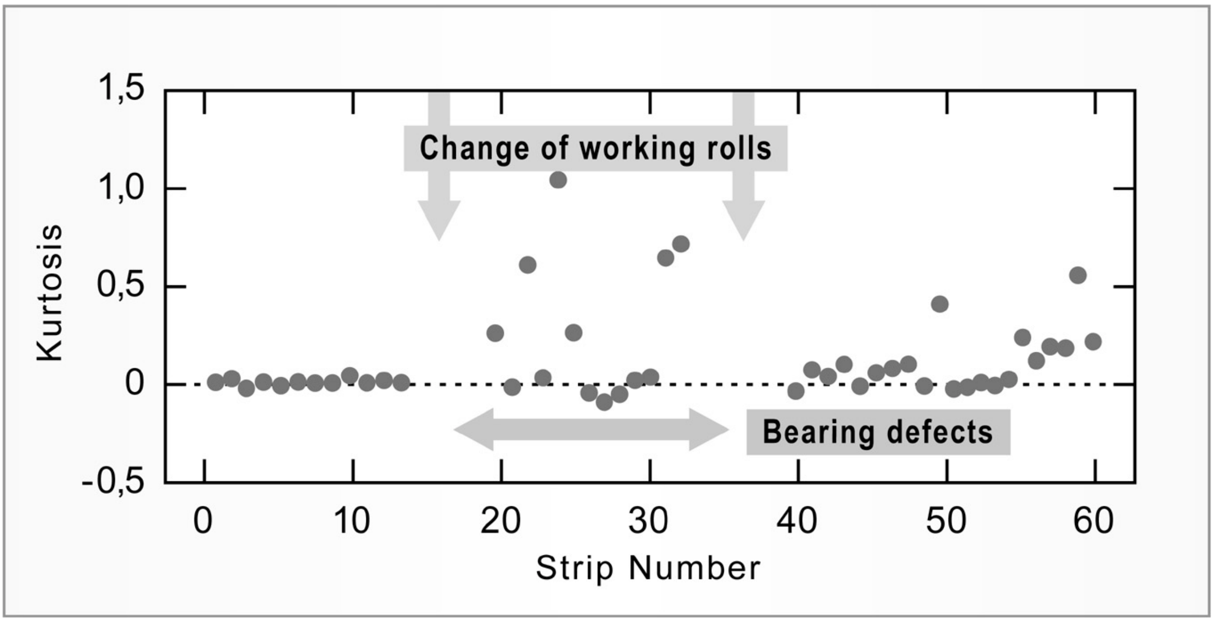

Fig. 6: Kurtosis analysis of rolling process with bearing defect

How sure can we be, however, that disturbance variables are not so-to-speak “imported” by the product itself or by changing machine components? As discovered at Bethlehem Steel on analysing numerous cases (5), chatter-generating vibrations do not just develop in the mill stand itself, but can be introduced whenever newly ground rolls are installed.

Using a very simple method, pressing a piece of wet chalk tangentially on the roll barrel during grinding, it was demonstrated that when grinding was completed, there were already periodic marks on the roll surface (fig. 7). These otherwise scarcely visible irregularities can cause considerable resonance when the rolls interact in the stand or come into contact with the strip being rolled. Knowing this, the task facing quality assurance staff is to equip lathes and grinding machines with vibration monitoring or suitable damping equipment to control the roll turning and grinding process.

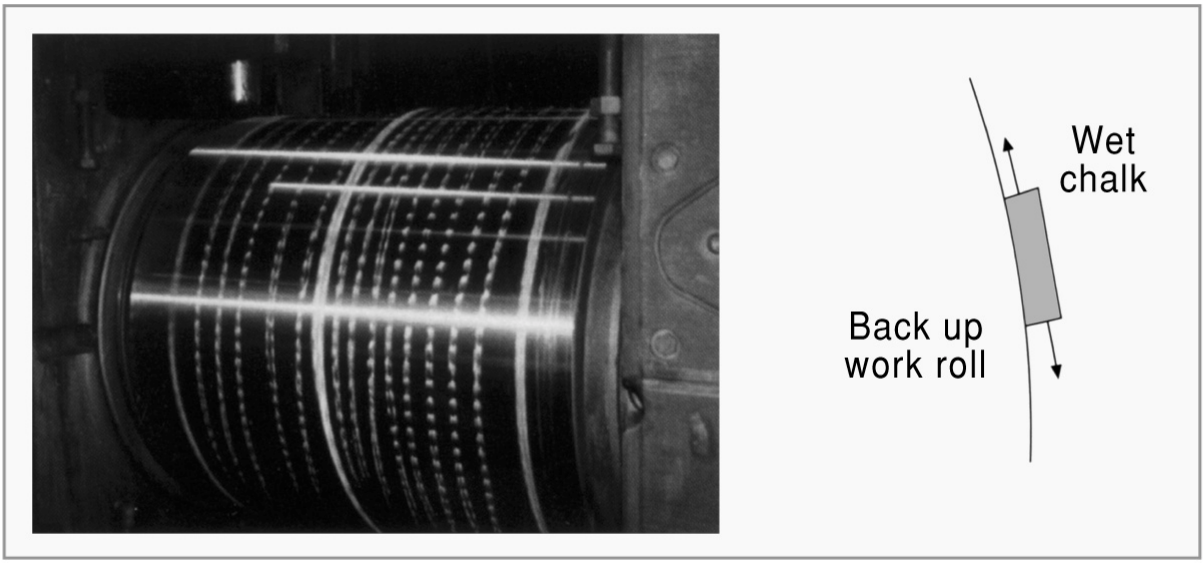

Fig. 7: Chalked backup Roll with grinder Chatter

For the steel industry it is clear that production-integrated measuring techniques such as the described vibration monitoring already represent the predominant category of installed monitoring systems. Maintenance and production engineers and technicians are usually familiar with the use, operation and maintenance of these systems as part of their daily work. These tasks do not call for a high degree of specialisation, but do require adequate skills.

Example "Multiple-process models"

The following example will show that it is nowadays possible to obtain numerous measured values from the actual steelmaking process for the purpose of equipment monitoring (6). This can be illustrated by the various stages that make up this process (fig. 8).

Together with a steel company, BFI, the research institute of VDEh, is developing a system which is able to determine the relationships between quality-characterising product properties and the influences affecting them at different process stages. The system is based on an extensive quality database, embracing all the process stages, and makes a multitude of tools available for the search relationships. Condition monitoring of mechanical components, as mentioned above for the rolling stage, is included in this model for assuring works-wide quality aspects. Employed in this respect, besides graphic and simple statistical techniques, are methods of multivariant statistics and computational intelligence.

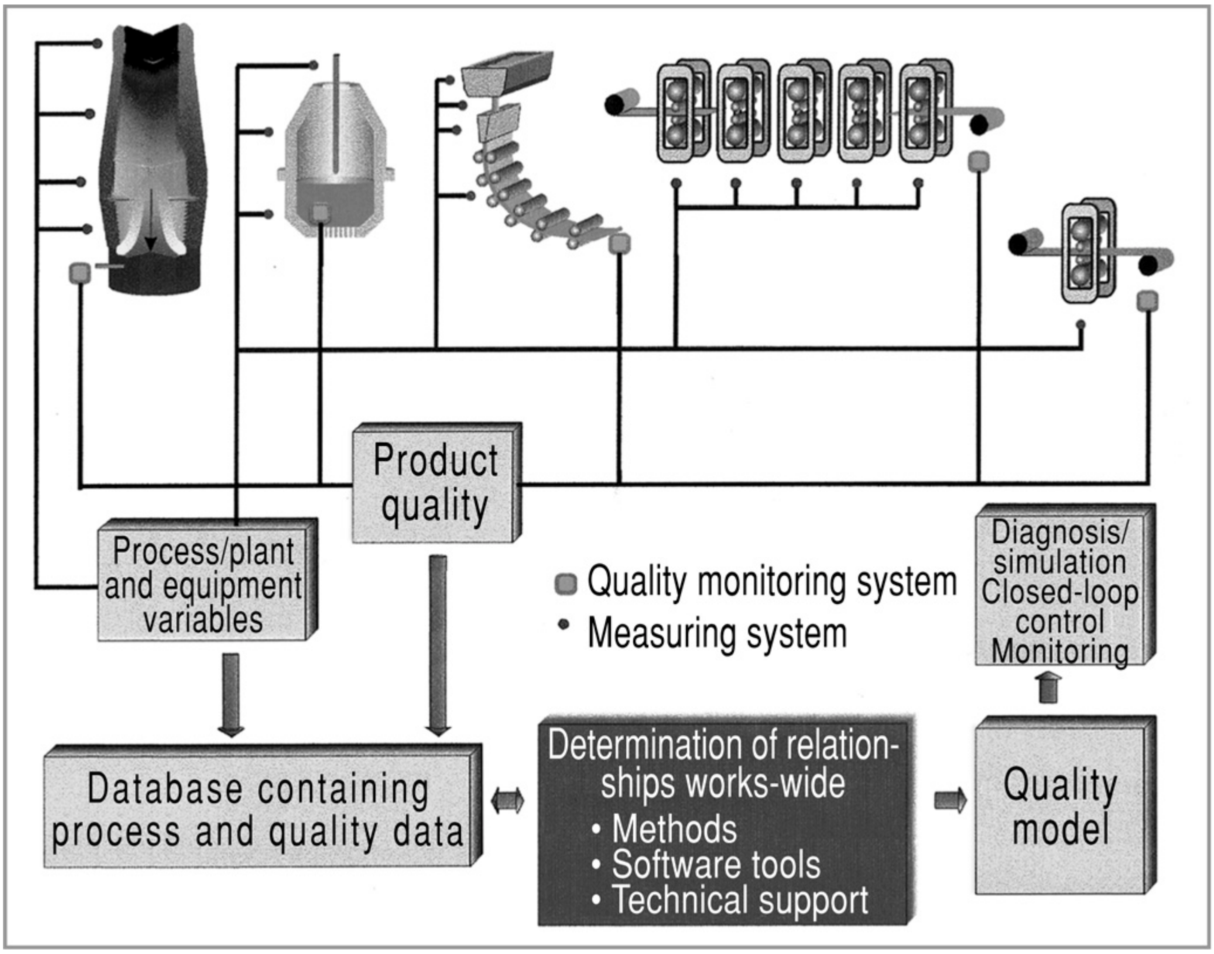

Fig. 8: Influences of Different Process Stages on Product Properties

The next example, a continuous caster as one link in the overall steelmaking chain, reveals the basic principle of the quality control loop (fig. 9): The automatically or manually logged product quality data and any feedback from downstream process stages (eg surface inspection of the cold strip) are mapped to the process variables logged on-line. This produces a product quality model that then forms the basis for a master quality control loop (6). The measured data input into the quality control loop serves to directly regulate the process. These signals from the sensors monitoring the actual continuous casting process can, however, also be used to derive data for **maintenance action**, such as the necessity to change continuous casting rollers, spray nozzles or complete segments.

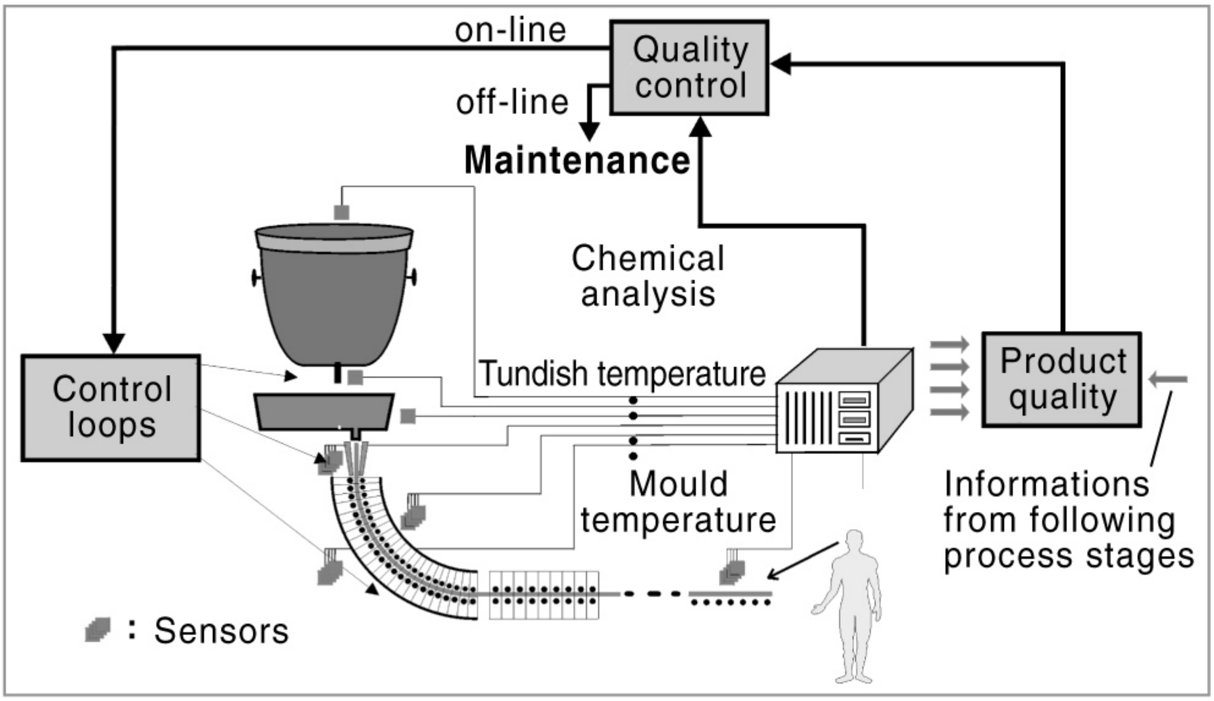

Fig. 9: System of Quality Control Loop at a CC-Plant

Objective: "Technical Safety"

Another parameter governing the continued process capability of production plant is ensuring its technical safety. This is another task for maintenance, where machine monitoring is essential. Both the machine manufacturers and the operating industry are legally obliged to take action here by the European Machinery Directive (98/37/EC).

Annex I to the Machinery Directive lays down the essential safety and health requirements applicable to the design and construction of machinery and safety components. The text reads as follows (section 1.1.2. Principles of safety integration): "Machinery must be so constructed that it is fitted for its function, and can be adjusted and **maintained** without putting persons at risk when these operations are carried out under the conditions foreseen by the manufacturer." In other words, the technical safety aspect must be taken into account at the earliest possible stage, ie, when the machine is being designed. But the scope of these requirements is not limited to the construction and running of the machine. It also extends to the associated set-up, assembly, and maintenance steps. The aim behind the Directive is to assure the **safety** of any person approaching the machine in the course of its lifetime.

Section 1.3.2 of the Annex stipulates particular protection measures against mechanical hazards, eg, with regard to material fracture. To quote from the text "The manufacturer must indicate in the instructions the type and frequency of inspection and maintenance required for safety reasons. He must, where appropriate, indicate the parts subject to wear and the criteria for replacement." This provision leads up to section 1.6.1 of the Annex, which, among other safety requirements, contains the following rule: "In the case of **automated machinery** and, where necessary, other machinery, the manufacturer must make provision for a connecting device for mounting **diagnostic fault-finding equipment**".

On the one hand, there is a positive aspect to the way in which the safety requirements of the Machinery Directive are thus directly linked to maintenance. On the other hand, this approach raises the question of what kind of diagnostic functions the aforementioned interface is supposed to serve. On conventional machinery it would appear fairly easy to implement one or more permanently installed sensor points for diagnostic purposes. In sophisticated production lines of the type used in steelmaking, diagnostic functions intended to ensure the technical safety of plant and equipment constitute a very complex problem, if only because such diagnostics must provide information not only on the momentary behaviour of equipment.

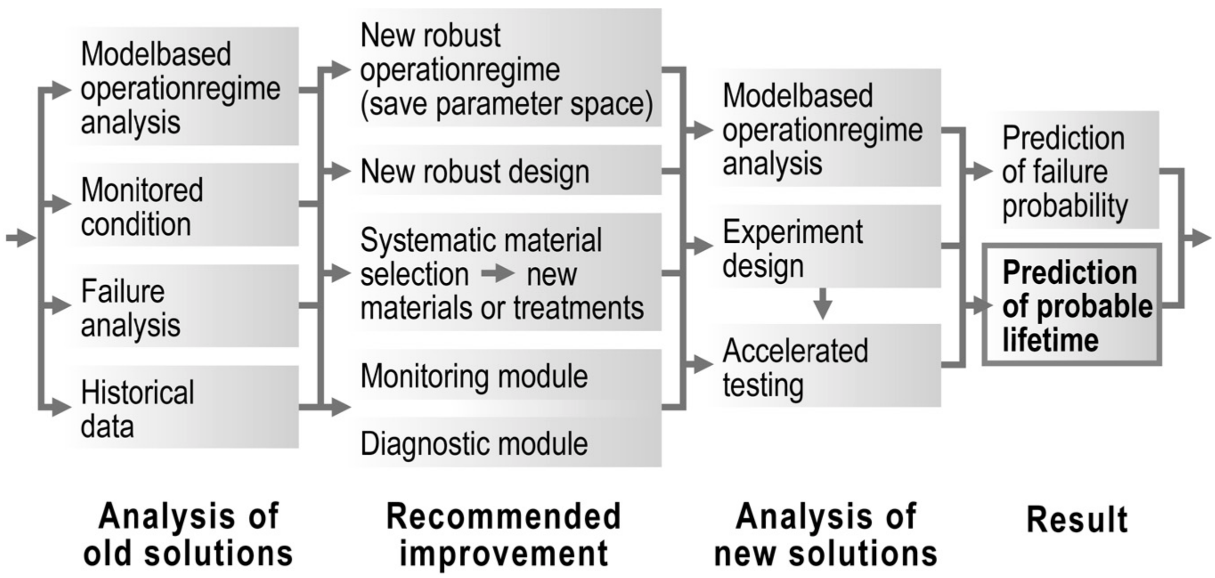

Fig. 10: Measurements for improved failure probability and lifetime

Fatigue Life Improvement

It is precisely in the field of technical safety that we have got to see numerous disillusions: In technical literature on this subject you may find a picture (fig. 10) showing “recommended improvements” which would, with the help of diagnostics, lead to the prediction of the probable lifetime of equipment (7). In the design and operation of steel industry’s equipment, it is still regrettably rare to consider these systems as **dynamically** loaded systems. The fatigue limits of our machine construction materials under vibrating loads are relatively low compared to their static characteristics. In many cases, however, loads above these limits have to be accepted for technical and economic reasons. If the loads exceed the fatigue strength, the component will always have a **finite life**.

The task facing the engineer is therefore to design and dimension the components such that their lifetime will, with a high degree of probability, reach or exceed the required service life under real operating conditions in the field. Even when a crack has been detected in a component, it will frequently have a considerably residual life before it ultimately fails. The object is to utilise this remaining lifetime, while still guaranteeing the technical safety of the equipment.

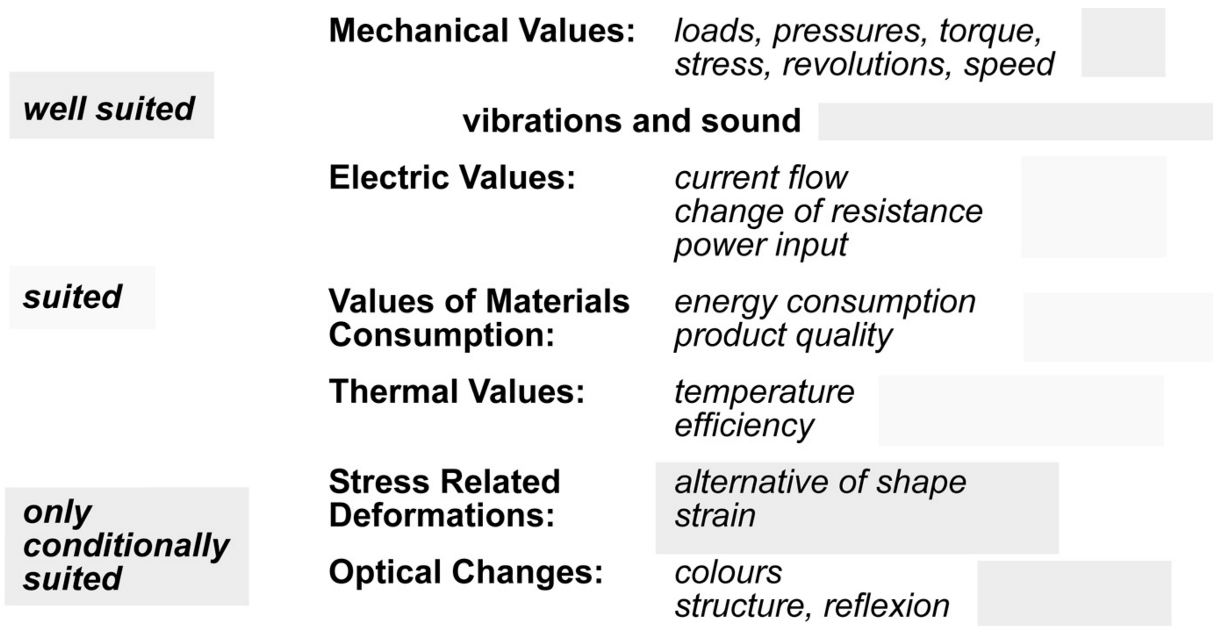

Fig. 11: Measuring Values and their Suitability for Machine Monitoring

While international literature considers the measurement of mechanical values as a suitable means of condition monitoring (3), the measurement of deformations (alteration of shape or strain) is still regarded as “only conditionally suited” (fig. 11). The conversion of such measurement results into the desired load parameters (force and torque) is only possible with elastic deformations. Establishing the relationship between the load acting on the part and the deformation measured already requires complex equipment. The situation becomes even more difficult when several load factors are acting simultaneously on the component. Distinguishing these factors in the measurement result requires very sophisticated instrumentation. The point of measurement itself is often solely governed by the local conditions, which are particularly unfavourable in the type of plant used in the steel industry. In addition, the proportionality between the measured local strain and the external load acting on the components presupposes that one can neglect their intrinsic dynamic behaviour.

Another point to remember is that, as elements of a machine system, the dynamic response of the individual components depend on the loads acting on the entire system and on the dynamic response of the system as a whole. The system loads are caused by the work process to be accomplished by the plant, the input parameters and the operating mode. In drive systems, another point has to be considered, ie their behaviour is not solely governed by the mechanical part, but also by the controlled electrical drive components. The same applies to hydraulic and other equipment. Component loads are thus not only not identical to those of the system; in many cases they are not even similar. Different components within **one single** system will often have very different load profiles and peaks, which can be illustrated by the measurements taken on a heavy reversing rougher train drive in a rolling mill (fig. 12) (8). All these factors have to be taken into account in condition monitoring.

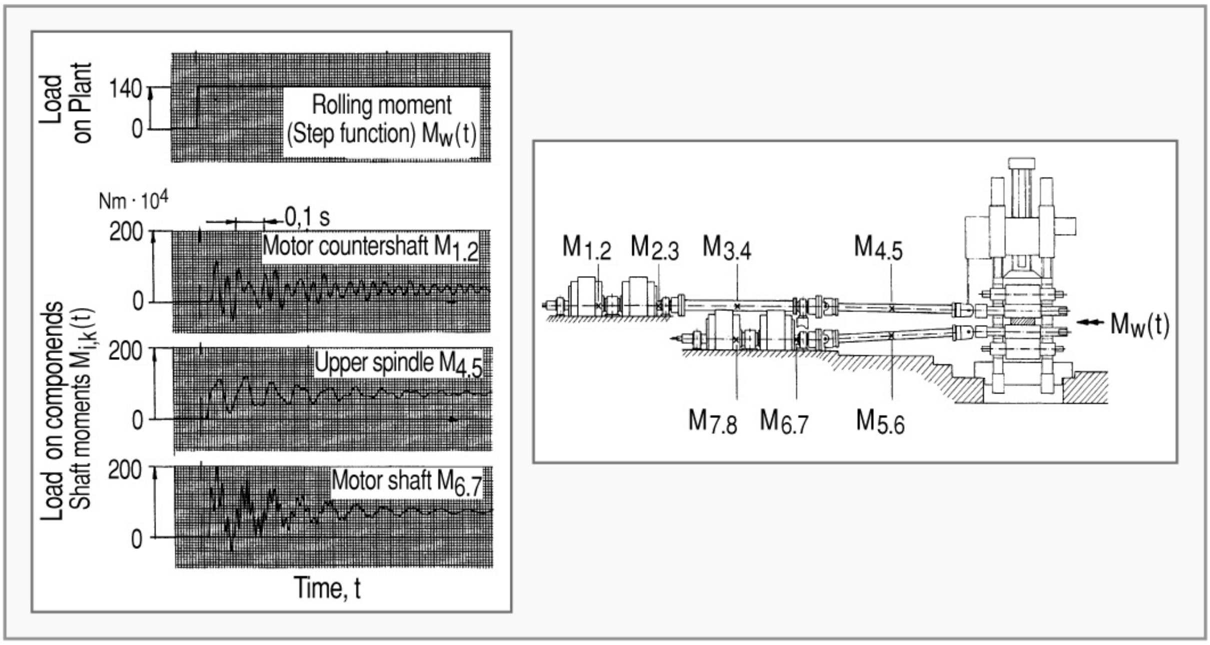

Fig. 12: Load at 3 Shafts of a Rolling Mill Drive at the Initial Pass

Model-based computer **simulation** of the real dynamic responses of machine systems frequently appears more promising. However, the quality of the calculation results depends very much on the quality of the model and the simulation of the system loads as they vary over time. The creation of such models and the performance of simulation computations demands extensive experience and a high level of expertise. Moreover, the simulation results have to be verified by **physical measurement** on the respective system.

Operational fatigue studies, calculations and simulations of this kind are not basically new. They were initially introduced in aircraft and car manufacturing more than 60 years ago. However, since the steel industry does not generally employ series-produced machines and components but mainly individually-designed plants and systems, as is usual in heavy industry, the operational fatigue approach and its application can only be established to a limited extent.

The wish to utilise the experience gained with series-produced components and to obtain sufficient expert knowledge in this area for sensible condition monitoring strongly conflicts with the, at times, very short-term corporate strategies applied in our companies. It is another disillusion that such short-term strategies sometimes accord only minor importance to the maintenance of long-lived production equipment, since it is often assumed that these services no longer form part of the company's core business.

Hopes regarding the organisation and judgement capability within the company

The success of condition monitoring in maintenance not only depends on technical aspects, but is largely determined by organisational structures. Often, even the best techniques will achieve limited success when the organisation is not suited to their application.

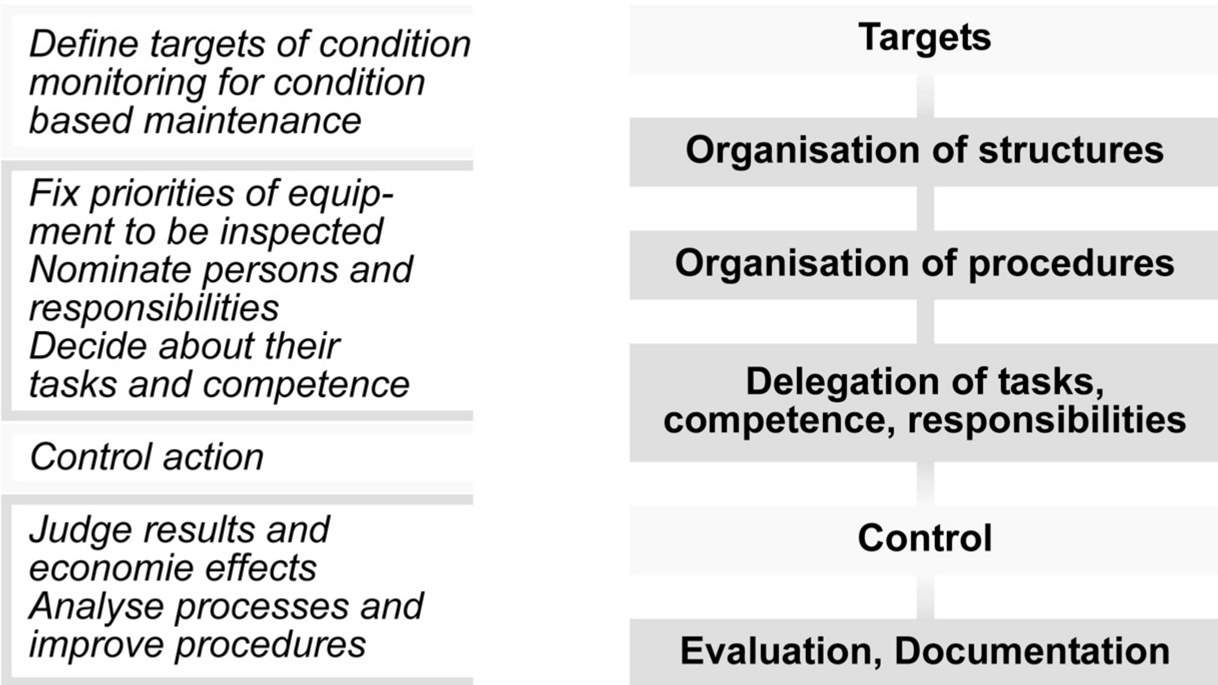

Fig. 13: Organisation Criteria for a Succesfull Monitoring

Fig. 13 shows the main organisational criteria for effective application of condition monitoring. First the targets have to be defined, then the persons concerned nominated according to their qualifications (9). The individual process and its steps have to be clearly described. The tasks and competencies of the persons involved also have to be defined and unanimously accepted, and the performance or target achievement of condition monitoring itself be monitored.

This hope to establish condition monitoring as part of plant monitoring is often faced with a quite different reality. An increasing number of manufacturers or sales organisations are offering or enthusiastically promoting instruments and components for machine diagnosis, which anyone having responsibility for production, and especially maintenance professionals, would ideally like to have. However, the suppliers deliberately suppress the fact that these instruments can only be properly operated by appropriately qualified personnel (10). In talks with top management, claims such as the following are made regarding new measuring techniques and instruments:

- They require no knowledge of the machines to be monitored or their components.
- No knowledge of the plant history is necessary.
- The equipment is suitable for all industrial environments.
- Diagnosis of every operating condition is possible; diagnosis results are not affected by the various operating conditions.
- Times to failure are reliably predicted.
- Measurement results need no interpretation or explanation.
- Diagnosis is based on expert systems and thus fully automatic.
- Ultra-simple handling means that the systems can be operated by even untrained personnel.

If such suppliers succeed in capturing the attention of top management with their dubious claims, the latter begin to doubt whether their maintenance engineers have not missed the boat or are even refusing to move with the technical times. Anyone in our companies desiring progress in machine monitoring therefore not only has to have sound technical arguments at hand, but also be capable of competently rejecting such unqualified and questionable proposals.

I hope my presentation has shown that there are a great many good reasons for sensible application of machine monitoring in maintenance as well as convincing arguments for its efficiency in relation to the overall profitability of the company. However, it is up to us to tackle the subject to ensure that the many hopes may quickly become a reality.

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